Status and Context of High Altitude Precision Aerial Delivery Systems

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Over the last several years, research funding has been applied to developing autonomously guided parachute systems as one part of the technology to meet the challenges posed by two critical threats: 1) the proliferation of Man Portable Air Defense Systems (MANPADS) that threaten aircraft conducting low-altitude supply missions; and 2) the parallel proliferation of threats to ground supply lines. This paper will survey the most prominent precision delivery guided airdrop systems in development and/or limited operational use today. User performance requirements and capability goals will be discussed. Flight test and operational experience will be briefly reviewed, as well as future deployment plans. The paper will conclude with a characterization of how well existing systems meet the user needs, and what GN&C-related technical capabilities still need advancement.

Nomenclature

AAA	Anti-aircraft Artillery
AGAS	Affordable Guided Airdrop System
AGL	Above Ground Level
AGU	Airborne Guidance Unit
CARP	Computed Aerial Release Point
CASCOM	Combined Arms Support Command
CDD	Capability Development Document
CDS	Container Delivery System
CENTCOM	Central Command
CEP	Circuler Error Probable
COTS	Commercial Off The Shelf
DoD	(US) Department of Defense
DZ	Drop Zone
ECDS	Enhanced Container Delivery System
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
GUI	Graphical User Interface
HMMWV	High Mobility Multi-Wheeled Vehicle
IMU	Inertial Measurement Unit
JFCOM	Joint Forces Command
JPADS	Joint Precision Airdrop System
JPADS-MP	Joint Precision Airdrop System Mission Planner
LIDAR	Light Detection and Ranging (aka laser radar)
LOC	Lines of Communications
MANPADS	Man Portable Air Defense Systems
MSL	Mean Sea Level
JMUA	Joint Military User Assessment
PADS	Precision Airdrop System
PATCAD	Precision Airdrop Technology Conference and Demonstration
PI	Impact Point

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PID	Proportional, Integral, Derivative
PM-FSS	Product Manager - Force Sustainment Systems
PPS	Precise Positioning Service
RAD	Ram Air Drogue
RC	Remote Control
RFP	Request for Proposals
RS	Ring Slot
SAASM	Selective Availability, Anti-Spoofing Module
SOCOM	Special Operations Command
SODAR	Sound Detection and Ranging
UAV	Unattended Aerial Vehicle
UHF	Ultra High Frequency
UK	United Kingdom
USAF	United States Air Force
USMC	United States Marine Corps
UTRI	Unmanned Technologies Research Institute
WSADS	Wind Supported Aerial Delivery System
YPG	Yuma Proving Ground

I.   Introduction

Current military operations often encompass expansive, non-contiguous territories that are time/distance sensitive and subject to an asymmetric threat. Employment of forces calls for significant dispersion, extending units from supply bases and extending the Ground Lines of Communication (LOC). These conditions are likely to persist given the propensity of terrorist elements to disperse, utilizing difficult and compartmentalized terrain to mitigate the informational and maneuver overmatches presented to them by U.S. forces. Sustaining our forces under these conditions presents considerable challenge.

The proliferation of Man Portable Air Defense Systems (MANPADS) and other non-traditional methods presents a serious risk for our airmen and soldiers conducting our re-supply operations. While LOC security is never guaranteed, insurgent forces are able to continually interdict supply lines and the convoys that utilize them. The result of this action is twofold. Enemy action is targeted at non-armored, combat service support vehicles, often with devastating effects. Mitigation of the enemy's ability to interdict the LOC is met by application of combat power to LOC security; ensuring freedom of movement for our supply operations but robbing the fighting force of operational flexibility.

Similarly, there are significant risks and shortfalls associated with conducting conventional air-drop operations. US Air Force (USAF) aircraft cannot meet USAF and Army accuracy standards once drop altitudes exceed 2000 feet above ground level (AGL). While drops below this altitude are more accurate, they are subject to a threat environment where small arms, Anti-Aircraft Artillery (AAA) and MANPADS are most effective.   Without precision high altitude airdrop ballistic and guided system technology, U.S. forces cannot safely or accurately conduct airdrop without risk to both aircraft and/or ground personnel.

Over the last several years, research funding has been applied to developing autonomously guided parachute systems as one part of the technology to meet the challenges posed by two critical threats: 1) the proliferation of MANPADS that threaten aircraft conducting low-altitude supply missions; and 2) the parallel proliferation of threats to ground supply lines. This paper will survey the most prominent precision delivery guided airdrop systems in development and/or limited operational use today.   User performance requirements and capability goals will be discussed. Flight test and operational experience will be briefly reviewed, as well as future deployment plans. The paper will conclude with a characterization of how well existing systems meet the user needs, and what GN&C-related technical capabilities still need advancement.

A key element of the airdrop mission is a mission planner. The JPADS Mission Planner (JPADS-MP) is an Air Force program that consists of a laptop computer with airdrop mission planning software along with a GPS retransmission kit for the interior of the aircraft and a dropsonde capability which provides real-time weather information just prior to an airdrop. JPADS-MP assimilates weather information from various sources, plans an airdrop mission, provides the information to the aircrew and also wirelessly to the decelerator systems. JPADS-MP can provide new winds, new release points and new landing coordinates any time prior to system deployment from the aircraft.   JPADS-MP will be the standard USAF mission planner; developers of airdrop systems are encouraged to become compatible with it. [Ref. 3]

II.   Key User Requirements

The US Army Combined Arms Support Command (CASCOM) represents the airdrop user. CASCOM is currently staffing a Capability Development Document (CDD) for 2,000-pound- and 10,000-pound-capable precision airdrop systems. To provide a general sense of user needs and the challenges that autonomous airdrop systems must overcome, Table 1 summarizes the important performance requirements from the CDD. Note that these are draft requirements, subject to change.

Performance Parameter	Weight Class	Development Threshold	Development Objective
Probability of successful airdrop	Both	0.95 without system abort	0.95 without system abort
Release altitude from fixed-wind air carriers	Both	24,500 feet MSL	35,000 feet MSL
Release altitude from rotary-wind air carriers	2K	10,000 feet MSL	Up to air carrier operational ceiling
Impact Point (PI) Accuracy	2K	Within 150 meter radius of PI at 80% frequency	Within 50 meter radius of PI at 90% frequency
	10K	Within 250 meter radius of PI at 80% frequency	
Fully rigged weight	2K	From 700 lbs to NTE 2,400 lbs	From 501 lbs to NTE 2,400 lbs
	10K	From 7,000 lbs to NTE 10,000 lbs	From 5,001 lbs to NTE 10,000 lbs
Navigation	Both	Commercial GPS	Military GPS-PPS with SAASM
Horizontal offset from 24,500 feet AGL	Both	5 KM	25 KM
Navigation waypoints	Both	1	3
Payload safety at ground impact	Both	Survive 17 knot winds	Survive 25 knot winds
Payload mission capability upon ground impact	Both	85%	> 85%
Airborne Guidance Unit Reuse	Both	20 missions	30 missions

Table 1: Important Performance Parameters from Draft JPADS CDD

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III. Current Precision Airdrop Systems

A. Affordable Guided Airdrop System (AGAS)

The Affordable Guided Airdrop System (AGAS) 2,200-pound capable system is being developed by Vertigo, Inc. and manufactured and marketed by Capewell Components Company, LLC. It utilizes standard military G-12 (ballistic, round) parachutes, achieving directional control via "riser slips" that deform the parachute as would a paratrooper. This affords a modest glide ratio, around 0.5. It is compatible with the Container Delivery System (CDS) without parachute or payload modifications. (The risers are replaced with extensions that connect to the Kevlar control risers from the AGU.) A mission plan establishes a trajectory based on the glide capability and adjusts the Computed Aerial Release Point (CARP) to reflect expected winds. AGAS is compatible with the JPADS-MP so multiple wind sources can be included in the trajectory formulation, including forecast, drop sonde, pilot reports, or direct relay from a ground station [Ref 3]. With such a low glide ratio, AGAS' guidance approach is quite simple. During flight, whenever the current position error exceeds a set amount from the planned trajectory, the control system drives AGAS back toward the plan. AGAS has had over 100 drops, from altitudes up to 25,000 feet MSL. Landing accuracy is generally within a 100 meter CEP. Use of standard military parachutes (the G-12, 64-foot diameter flat round cargo parachute) that are produced in great quantity makes AGAS very inexpensive. AGAS has been successfully tested using a military GPS receiver. 500-pound- and 4,000-pound-capable AGAS systems are under development. The 82nd Airborne Division has expressed keen interest in acquiring AGAS for aerial re-supply. Various Rapid Fielding Initiatives (RFI) are under consideration that could result in fielding of AGAS systems.
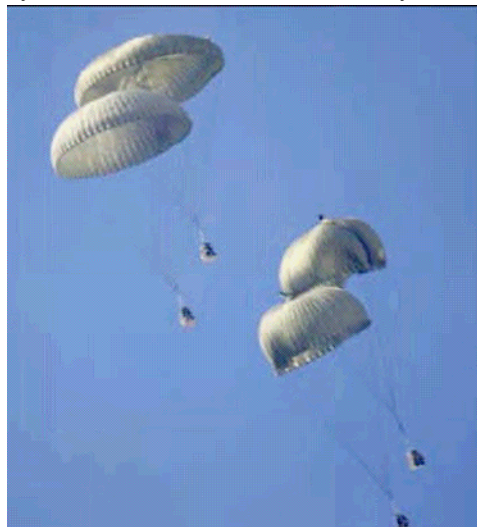
B. Controlled Aerial Delivery System (CADS)

The Controlled Aerial Delivery System (CADS) 500-pound capable system is a product of Flight Refueling Ltd. of the UK. This parafoil system follows an RF signal to either home to a ground beacon or to respond to remote control (RC) commands. Via the RC link, a following parachutist can control the system, or a ground controller can guide the system to the target. In this mode a manual flare can be accomplished for accurate, soft landing. The parafoil has a glide ratio of about 3.8, affording an 18-mile offset from 25,000 feet AGL in zero winds. There are about 75 systems in operational use by UK and Japanese forces, and over 600 drops have been conducted. Autonomous landing accuracy is around 100 meters, and manual landings of 50 meters are achievable. A 2000-pound-capable system is in the planning stages, as is a fully-autonomous GPS guidance capability.

C. Dragonfly

The *Dragonfly* [Refs. 1, 2] 10,000-pound capable ram-air parafoil system was developed by a contractor team led by Para-Flite, Inc., provider of the canopy and rigging. Wamore, Inc. provided the Airborne Guidance Unit (AGU), Robotek Engineering the avionics, and Draper Laboratory developed the GN&C flight software. *Dragonfly* is compatible with Enhanced Container Delivery System (ECDS), Type V, and 463L platforms. With a glide ratio in excess of 3.1, *Dragonfly* can provide nearly 14-mile offset capability from 25,000 AGL in zero winds. A dual-channel CSI Wireless GPS receiver is the sole navigation sensor. After a stable canopy opening, state estimates derived by filtering the position, velocity, and heading inputs from the Navigation package are utilized by Guidance to begin directing the control algorithms to steer the system toward the target. When the airdrop system comes within about 200 meters horizontal distance from the target, it enters an Energy Management mode, flying figure eight patterns in the vicinity of the target until ground-relative altitude drops below 500 meters, at which point it steers directly toward the target to establish the final approach. From this point until landing, the Guidance software utilizes pre-computed steering commands from a look-up table with a large family of trajectories designed to minimize final position and heading error. This table-driven approach minimizes the trajectory determination processing burden on the available, small, low-throughput flight processor. Using gain scheduling, the Proportional, Integral, Derivative (PID) Controller tracks the heading commanded by Guidance and attempts to maintain symmetric retraction of the control lines about a baseline toggle setting. *Dragonfly* is compatible with the JPADS-MP so multiple wind sources can be included in the trajectory formulation, including forecast, drop sondes, or pilot reports [Ref 3]. There have been over 40 fully autonomous drops, with landing accuracy generally within 200 meters.   Direct development work on *Dragonfly* ceased in October 2005. It is currently serving, however, as a subscale test asset for a 30,000-pound-capable parafoil development sponsored by the US Army, Natick Soldier Center. Besides the scale-up to 30,000 pounds, this new system will have enhanced avionics, dropping the dual-channel GPS in favor of a single GPS augmented by an inertial navigation system for full 3-axis attitude sensing.
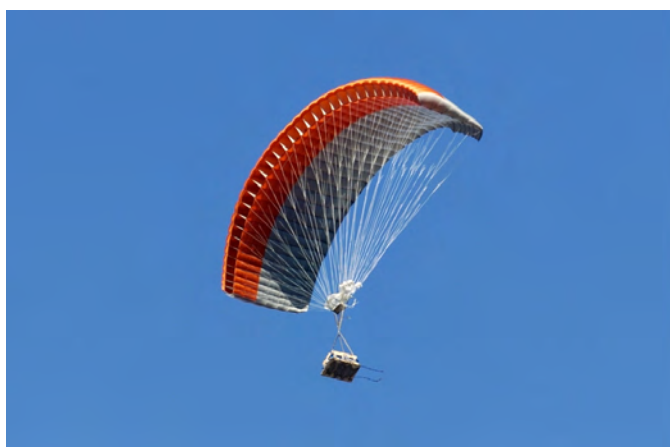
D. Firefly

The *Firefly* 2,000-pound capable ram-air parafoil system is very similar to *Dragonfly*, and is under development by Para-Flite, Inc., providing the canopy, rigging, and GN&C software, Wamore, Inc., providing the AGU, and Applied Micro Design providing the avionics.   It is GPS-guided and fully autonomous. It is not yet integrated with the JPADS-MP, though there are plans to do so. It has a glide ratio of about 4.1, providing an offset capability of around 19 miles from 25,000 AGL in zero winds. *Firefly* has flown over 100 times, with a landing accuracy around 100 meter CEP.

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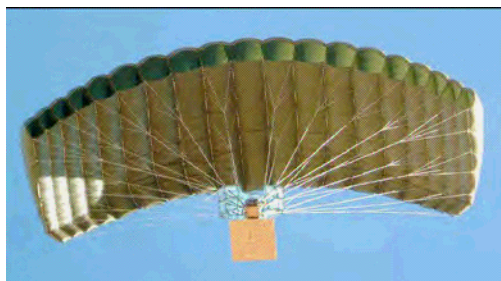
E. Mosquito

Built by STARA Technologies, the *Mosquito* is one of only a handful of autonomously-guided airdrop system currently capable of launch from an Unattended Aerial Vehicle (UAV). Capable of dropping payloads between 3 and 150 pounds, it is designed for delivery of critical supplies (e.g., blood to an injured soldier), for implanting unattended ground sensor packages (chemical, seismic, acoustic), or placement of anti-tank sub-munitions. The *Mosquito* may be hand-tossed out a troop door of a C-130 or C-17 aircraft, off the rear ramp, or dropped from a UAV. The same guidance unit supports packages up to 150 pounds with a parafoil change. System glide ratio is around 3:1. *Mosquito* has flown over 500 times and has been released from altitudes up to 10,000 feet. Average target landing precision is below ten meters, due to recent innovations in the guidance algorithm. The *Mosquito* uses an open loop, proportionally controlled guidance algorithm that blends GPS data with an onboard inertial measurement unit to calculate the navigation solution. The Navigation software runs at 100Hz. The system behaves very well in windy conditions.

F. Onyx

Built by Atair Aerospace, Inc., *Onyx* is a family of HALO (high altitude, low opening) hybrid precision airdrop systems that utilizes a high-efficiency elliptical parafoil to rapidly steer to the ground target, where at ~125 meters it releases a round recovery parachute for final ballistic descent to the target. The three weight classes are 0 – 20 lbs (*Micro Onyx*), 20 – 500 lbs (*Onyx 500*), and a 500 – 2200 lbs (*Onyx 2200*) capability is also under development. Unique features include the ability for formation flying, active collision avoidance, and adaptive control (self-learning functions for varying cargo weights). *Onyx* will likely be integrated with the JPADS-MP beginning October 2006. Various *Onyx* systems have flown over 100 times, from altitudes up to 15,000 feet. A glide ratio of 4:1 provides significant horizontal offset capability. Landing accuracies of 75 meters have been achieved.

G. Panther

Pioneer Aerospace, developer of parafoils for NASA's X-38 Crew Return Vehicle project and numerous aerodynamic decelerator systems for interplanetary missions, has entered the military cargo market with the *Panther* family. *Panther*-500 supports weights from 200 to 500 pounds (for the A-7 military CDS container), and Panther-2500 supports the 500 - 2500 pound range (A-22 class). The mission includes course tracking to the target after carrier aircraft deployment, waypoint navigation (if selected), a holding pattern above the target to lose altitude, and then executing a final approach into the wind which can include a flared landing. The system also has a "wind abort" mode to handle extreme wind conditions, during which it holds upwind until the wind decreases, or until it must turn toward the landing point. Various *Panther* systems have flown about 70 times, from altitudes up to 10,000 feet MSL. A glide ratio of 3-3.5 provides significant horizontal offset capability. Landing accuracies of less than 150 meters are generally achieved. Landing direction is selectable, or in the autonomous mode will orient the final approach pattern for a headwind landing. A flare and flare profile is selectable.
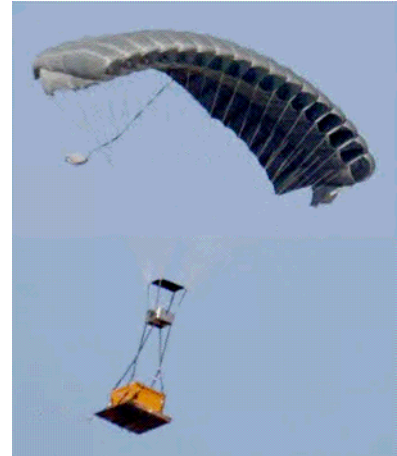
Although compass-equipped, compass operation is optional. The system generally flies with GPS as the only navigation sensor – the flight algorithms are sufficiently sophisticated to permit GPS-only flight at wind speeds greater than the vehicle airspeed. In-flight algorithms generate continuous wind estimates for autonomous, real time in flight planning. A PC-based mission planner also provides for remote manual operation, pre-flight mission simulation, post flight mission playback, and continuous data download. Numerous optional maneuvers can be selected for the mission profile to include wind turns, calibrations turns, and glide ratio optimization. The *Panther* AGU can be programmed wirelessly or through a serial cable.

H. ParaLander

European Aeronautic Defense and Space (EADS) has developed the 1100-pound capable *ParaLander* guided parafoil cargo airdrop system with a rather unique guidance approach, derived from the personnel parachuting methods. Based on forecast winds, the mission planner computes a release cone that accommodates the glide capability of the parafoil, and a ballistic (round parachute) trajectory toward the ground target. This then allows the system to, in paratroop parlance, "drive toward the wind line." If the system is released close to this ballistic canopy trajectory the navigation computer will fly in the general vicinity of the ballistic canopy trajectory in order to burn altitude. As the release offset is increased (within the operational funnel) the system will fly in a more direct path to achieve the ballistic canopy line at a lower altitude. The goal is to release along the outer edges of the operational funnel and the system should reach the ballistic canopy line at approximately 2000 ft AGL.

At a predetermined altitude the payload's center of gravity is shifted more to rear risers causing a dynamic flare. This results in a soft landing without the need for an actuator-induced flare maneuver. *ParaLander* also has the capability to receive alternate landing site information while in flight, and can be remotely steered from a ground station. *ParaLander* has a glide ratio of 2.75:1 and has been dropped 23 times from altitudes up to 10,000 feet MSL. Average landing precision is around 100 meters.

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I. Screamer

The Screamer family of systems is being developed under US Army NSC contracts by Strong Enterprises with RoboTek Engineering, Inc. supplying the AGU and GN&C software. There are 2K and 10K variants that use the same AGU and software. *Screamer* is a modified HALO hybrid aerial delivery system. It autonomously navigates during ram air drogue (RAD) parafoil flight to a programmed target point in space in the vicinity of the target. It then descends in a circular pattern above the target to a preset mission recovery altitude at which time round cargo parachutes are deployed to arrest high-speed forward glide and affect a standard ballistic recovery descent. Preprogrammed knowledge of surface winds is applied to resolve a recovery parachute deployment location to ensure landing accuracy. *Screamer* is fully integrated with the JPADS-MP, allowing planning using multiple wind sources and enroute mission re-planning. During the RAD parafoil flight phase, the system reaches forward air speeds up to 100 mph, allowing effortless wind penetration under normal conditions. The RAD parafoils are loaded up to approximately 12 lb/ft2 of canopy fabric area. The RAD parachutes for both systems are Strong Enterprises designs, as is the Pocket G-12 recovery parachute for the 2K variant. The 10K uses a pair of conventional military G-11 parachutes for recovery. The use of commercially-produced round recovery parachutes makes Screamers less expensive than most parafoil solutions, and expendables are less that $100 per cycle. Besides compatibility with JPADS-MP planner, Strong has developed an alternative mission planning capability that can be used on non-JPADS-MP enabled aircraft. With either mission planner, *Screamer* can accept mission plans wirelessly via an 802.11g communication link. *Screamer* has been successfully tested using a military GPS receiver.

The 10K *Screamer* has been developed under the auspices of an Advanced Concept Technology Demonstration (ACTD). Initially in competition with the *Dragonfly* program, in July 2005 *Screamer* was chosen to be the 10K system that moved forward for further maturation and Joint Military User Assessment (JMUA). The first JMUA took place in June 2006. The third and final JMUA will take place in January 2007. Following that, and assuming a positive evaluation, residual assets will be transferred to the DoD for further refinement. Strong has sold 10 2K Screamers to SOCOM, are being evaluated extensively for possible rapid fielding. The 10th Mountain Division and the US Marine Corps (USMC) have expressed strong interest in using these systems in theater. Various Rapid Fielding Initiatives (RFI) are under consideration that could result in fielding of Screamer systems.

Table 2 compares key technical parameters of the two *Screamer* systems:

	2K Value	10K Value
Weight range demonstrated	700 - 2350 pounds	7,000 – 10,000 pounds
Deployment altitude achieved	24,800+ feet MSL	25,000+ feet MSL
Landing accuracy – typical	< 50 meters	< 100 meters
Glide ratio	2.1:1	2.5:1
System weight	138 lbs	830 pounds
Number of autonomous drops	> 200	> 100
Descent speed at max weight	~27 feet per second	~25 feet per second
Forward speed - typical	100 mph	70 mph
RAD canopy area	220 ft^2	850 ft^2

Table 2: *Screamer* Technical Parameters

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J. Sherpa

Mist Mobility Systems (MMIST) of Ottawa, Canada produces a family of commercial *Sherpa* guided airdrop systems, capable of delivering cargo ranging from 400 – 2400 pounds utilizing three different parafoils. With an average glide ration of 3:1, *Sherpa* systems can provide over 15 km of horizontal offset from 25,000 feet AGL, assuming zero winds. After main canopy deployment, *Sherpas* head toward the drop zone, guiding either to a pre-programmed target location or homing in on a radio beacon. In the terminal area, they can land into the wind or at a pre-designated heading. *Sherpa* has been integrated with the JPADS-MP, and has its own planner for use on carrier aircraft that are not equipped with JPADS-MP.

A number of military organizations have purchased *Sherpas*. In 2004, two 1000-pound capable systems were provided to the USMC under a CENTCOM Operational Needs Statement. These systems were deployed to Western Iraq where they were used to re-supply troops to offset some amount of truck convoy traffic. At least 16 operational drops were made. The systems were very successful in this harsh operational environment, and provided a landing accuracy of ~70 meters CEP. In December 2005 USMC received 20 2000-pound capable *Sherpas*, under a USMC Urgent Need Statement. These systems have been delivered and some are being used in theater today. Other users have also purchased *Sherpas* for potential use in theater as well. *Sherpa* has been successfully tested using a military GPS receiver.

Table 3 compares key technical parameters of the *Sherpa* systems:

	1200	2200
Weight range demonstrated	870-1400 lbs	1400-2400 lbs
Deployment altitude achieved	24,500 MSL	24,500 MSL
Landing accuracy – typical	<175 m	<225 m
Glide ratio	3.0	3.2
System weight	154 lbs	202 lbs
Number of autonomous drops	102	51
Forward speed - typical	52 fps	55 fps
Parafoil canopy area	900 sq ft	1200 sq ft

Table 3: *Sherpa* Technical Parameters

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K. Skyporter

Unmanned Technologies Research Institute (UTRI) of Italy is developing the *Skyporter* small bundle re-supply system with a payload range of 110– 440 pounds. *Skyporter* comprises a high-glide ram-air parafoil flown by UTRI's NEMO Mk II autopilot. The NEMO system uses an integrated GPS/INS to develop a navigation solution at a 10Hz update rate. The NEMO system is also used in UTRI's *Skypath* paratrooper guidance system, which supports formation flying and collision avoidance; these capabilities are available to *Skyporter* as well, and an in-air mix of personnel and cargo is supported. The GN&C processing includes on-board wind estimation. A soft landing flare capability is also available. UTRI has developed a laptop-based mission planner. An 802.11 wireless link to provide the mission plan to the AGU is under development. A ground station provides remote manual flight control of the system. Plans are in place to increase weight capability to 2000 pounds in 2007.


L. Smart Parafoil Autonomous Delivery System (SPADES)

Dutch Space of The Netherlands, in partnership with the National Aerospace Laboratory NLR, has developed the *SPADES* family of airdrop systems utilizing ram-air parachutes for autonomous delivery of payloads from 220 pounds – 2200 pounds. To achieve multiple weight classes, the *SPADES* systems use different parachutes, and have demonstrated the ability to fly parachutes from multiple manufacturers. The G9 parachute from Aerazur supports payloads up to 350 pounds, while their PBO tandem parachute supports payloads up to 550 pounds. Utilizing the *Firefly* canopy from ParaFlite, *SPADES* is capable of delivering payloads up to 2200 pounds. The glide ratios of these parafoils provide significant horizontal offset from the ground target. GPS is the sole navigation sensor, and only minimal prior wind knowledge is required for mission planning. Landing accuracies of less than 100 meters have been regularly achieved, and

a dynamic flare maneuver provides a soft landing capability. *SPADES* systems have been dropped over 80 times, from altitudes up to 26,600 feet MSL. S*PADES* has been deployed from three different aircraft (C-130, C-17, and C-160) flown by several different nations. Plans are underway for final modifications leading to operational status.

M. Snowbird

Also developed by MMIST, *SnowBird* is a derivative of the *Sherpa*. It provides a small bundle re-supply capability and comes in two sizes: the *SnowBird 150* can deliver from 50 lbs up to 150 lbs of cargo while the *SnowBird 400* is capable of delivering up to 600 lbs. They have a horizontal offset potential of 13 km in zero winds with wind penetration to 25 knots and maximum drop altitude capabilities of 25,000 ft MSL. Typical glide ratio is 2.4:1. The *SnowBird* has not yet been integrated with the JPADS-MP mission planner. It utilizes a proprietary Windows-based mission planning unit that incorporates impact point coordinates, payload weight, and wind data to determine the CARP and a flight path leading to the intended impact point (PI) on the drop zone. *SnowBird* systems have been dropped ~55 times and have achieved a maximum deployment altitude of 25,000 feet. As of this writing, four systems have been sold. Landing accuracies better than 50 m have been achieved.
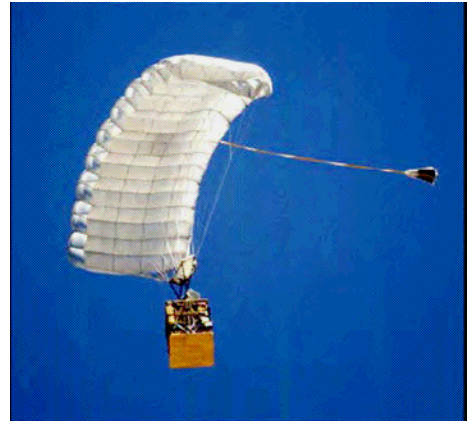
N. SnowGoose

Another MMIST product is the unique powered parafoil system *SnowGoose*. This system provides the advantages of airdrop as well as a significant horizontal range capability. Developed primarily for dropping PSYOPS leaflets, *SnowGoose* is an extremely versatile UAV capable of carrying and deploying up to 600 pounds of cargo. The cargo compartment contains six individual bays; each is separately-releasable and capable of handling 100 pounds of varied cargo. The cargo bays can be loaded with a great variety of material, including small bundle re-supply packages, unattended ground sensors, EO/IR sensors, communications equipment to be used for relay, or additional fuel to extend the UAV's range. *SnowGoose* can be air-launched like any other airdrop system, or ground-launched from a HMMWV. *SnowGoose* can autonomously fly pre-programmed missions with multiple waypoints, multiple cargo release points, and include loiter time as well. It uses the same AGU as *Sherpa*. A ground-to-air capability allows full human-in-the-loop mission execution. The Iridium satellite communications system can provide mission re-tasking from beyond line of sight. *SnowGoose* is currently in Full Rate Production with SOCOM and has been given the military designation CQ-10A. Another project-related designation for this system is Wind Supported Aerial Delivery System (WSADS). The first *SnowGoose* systems deployed in May, 2006

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IV. Flight Test and Operational Experience

Over the past three years, development of guided airdrop systems has accelerated, with concomitant heavy activity at test ranges in the US as well as in Europe. At the most recent Precision Airdrop Technology Conference and Demonstration (PATCAD) in October, 2005, 17 nations were represented, aircraft from three nations were used, and 115 airdrops executed. A smaller NATO-sponsored international airdrop demonstration took place in July, 2006 at Biscarosse, France. For initial testing, commercial ranges and aircraft have been used extensively at places like Eloy and Kingman, AZ. As systems mature, testing tends to shift to military aircraft and military ranges, most particularly Yuma Proving Ground, Yuma, AZ, where activity has been extremely intense over the last two years with no particular end in sight. All in all, over a thousand drops have been executed, with many systems having accomplished hundreds. Extensive instrumentation is used to support initial characterization of canopy performance, detailed performance of the GN&C flight software, determination of landing precision, and locating loads that sometimes go astray. The instrumentation used for any given test varies depending on individual objectives, often including ground-to-air video from multiple sites, radar tracking of the loads, on-board and/or telemetry recording of numerous software parameters, GPS position, and system attitude. Frequently, both the AGUs and the payloads have GPS and inertial state data recorded independent of the actual flight instrumentation. Much of this test instrumentation, as well as post-flight data analysis software, have been developed at US Army Natick Soldier Center. To more fully analyze system performance post-flight, local winds are characterized first by weather forecast, then also by the release of weather balloons from the DZ and/or drop sondes or other GPS-carrying small ballistic loads from the carrier aircraft. For reliability, redundant recording (on-board and telemetry) is often utilized.

There has been modest operational use of guided airdrop systems to date. As noted above, two *Sherpa* systems were deployed to Western Iraq in August, 2004, and around 30 *Sherpas* are now available for use by the US military. JFCOM, under a Limited Acquisition Authority with NSC, provided *Screamer* systems to SOCOM for operational use. The first *SnowGoose* systems deployed in May, 2006. The UK and Japan have deployed the CADS system as well. The US Army, Product Manager - Force Sustainment Systems (PM-FSS) has a program of record for acquisition of 2K-class guided airdrop systems scheduled to start 1QFY07. An RFP to industry is planned for late summer, 2006, and many responses are expected. In addition, because of the urgent need to meet the threats described in Section I, the US is pursuing a variety of means for deploying guided airdrop systems prior to formal acquisition. A Rapid Fielding Initiative to support CJTF-76 is now underway to procure, validate and deploy 2K *Screamer* systems. The USAF is also buying 2K *Screamers* for training in the US. The US Army NSC is pursuing Quick Reaction Funds to procure and deploy a substantial number of AGAS systems to support the 82nd Airborne Corps. As these guided airdrop systems are used operationally, it is expected that pressure will increase for even more system deployments.

V. Meeting User Needs

Making parachutes do what you want them to do, and go where you want them to go, is no trivial matter. "From an aerodynamic perspective, the analysis of a deploying parachute involves viscous, unsteady, turbulent, compressible wake-dominated flow over a continuously deforming geometry. The flow may also be supersonic. The porosity of the canopy further complicates the problem by allowing fluid to pass through the parachute material." [Ref 4] The requirements outlined in Section II are all achievable, though many challenges remain. The noted threshold release altitude requirements are well in hand for a good number of systems, as are the threshold weights. Meeting the lower weights within a range, however, with the same canopy as the higher, remains somewhat of a challenge, particularly for the objective values. Horizontal offsets are achievable, but at the cost of increased time in flight, which poses operational difficulties due to the need to clear the air space of other vehicles during the drop. Navigation with militarized GPS receivers is an engineering job that must be worked, but involves minimal technology development. The greatest challenges are overall reliability and landing precision. There is a lot of "touch labor" in manufacturing, packing, and rigging parachutes; small errors can ruin an air drop. A key part of reliability is in development of clear, thorough packing and rigging manuals, and extensive training of the individuals who will use the systems operationally. Knowledge of winds presents a great challenge for guided systems, and in some cases is the primary risk factor for landing performance. While many systems can land within 150 meters of a target from high altitude, doing so regularly and consistently is still a challenge for many systems. The objective accuracy requirements, 50 meters 90% of the time, are very challenging for most systems.

VI. Capabilities Needed

For high glide parafoils like *Dragonfly*, the timing of final flare maneuvers to reduce horizontal and vertical velocities during landing is critical to landing precision. A system with a 3:1 glide ratio that is descending at 20 feet per second covers 60 feet (~20 meters) along track every second. As most systems navigate primarily with GPS, the inaccuracy of the vertical channel thus poses a significant problem. Precision height sensors optimized for the airdrop mission, now under development, will be critical in helping these parafoils achieve desired landing performance. Such sensors must be able to sense the ground over a variety of terrain for broadest utility. This is indeed a challenge, and various sensing modalities have been tried, including laser ranging, radar altimeters, and Sound Detection and Ranging (SODAR). Hybrid systems, like the *Screamer*, need accurate timing of the release of the recovery parachute(s), from higher altitudes than the high glide systems, making it all the more difficult to determine ground height accurately over varied terrain. The key critical factor for hybrids, however, is knowledge of ground winds, since the final phase of flight is ballistic, when the system is completely subject to the winds. Real-time LIDAR wind sensors, carried on the dropping system, are a possible technology to overcome this difficulty. It is expected that such sensors would be helpful for high glide canopies as well. Finally, as GPS is the ubiquitous and primary navigation technology for all airdrop systems, one must consider what to do when it is not available, either due to enemy jamming or blockage by terrain (dropping in mountainous areas) or buildings (dropping into urban canyons). Development of small, inexpensive, reliable, inertial sensors with strategic-navigation-grade performance would provide an alternative in situations where GPS is denied. Much research on such sensors is underway.

VII.   Conclusions

Ten years ago, cargo airdrop was restricted to low altitude because no precision guided systems were available. The proliferation of threats to carrier aircraft made this situation untenable. Now, the technology for high altitude, precision landing is available, and the ability to design autonomous GN&C flight software for precision systems is proliferating. Challenges remain as requirements grow to require greater weight, from greater altitude, and to ever more accurate landings. This is an operational domain in great need of talented engineers ready to accept the challenges of developing such systems.

Acknowledgments

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